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Opportunities for Promoting Healthy Homes and Long-Lasting Energy-Efficient Behaviour among Families with Children in Portugal

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Abstract: Energy poverty vulnerability constitutes a significant concern in Portugal, with 17.5% of the population being unable to keep their home adequately warm. Furthermore, there is evidence that a substantial number of children live in unhealthy homes. This study aims to comprehensively characterise a sample of 101 Portuguese families with children and their homes in order to identify opportunities for actions for promoting long-lasting energy efficiency and environment health-promoting behavioural changes. To accomplish this aim, two tools—a building survey checklist and a questionnaire to participants—were developed and implemented to collect harmonised data on building-specific characteristics and on participants' socioeconomic status and behaviour. The home visits for recruitment and data collection were conducted from July 2021 to April 2022. The results suggest that, for the population under study, the main opportunities for improvement include: (i) replacing low energy-efficient technologies, with high emission rates, namely those used for heating purposes, with cleaner and more efficient alternatives; (ii) providing citizens with detailed information about their home's energy use and indoor air quality and (iii) educating the population on the best-practices for reducing indoor air stuffiness, mitigating the risk of hazardous exposures, improving thermal comfort and saving energy.

Keywords: building survey; children's exposure; designing interventions; energy consumption; indoor air quality

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1. Introduction

In 2020, the building sector accounted for 22% of global final energy demand, with residential buildings accounting for 17% of total direct and indirect energy related carbon dioxide (CO_2) emissions [1]. Decarbonising the residential building sector is a pressing issue due to its significance in overall energy use, but it also presents specific challenges in terms of adopting inclusive policies and addressing social inequality and energy poverty [2].

According to data from 2018, energy use by households in the International Energy Agency (IEA) member countries is primarily associated with space heating (53%), residential appliances (19%) and water heating (16%) [3]. Space cooling (4%), cooking (4%) and lighting (2%) make up the remaining major energy consumption activities in households in the selected IEA countries [3]. In particular, in Portugal, energy poverty constitutes a significant concern due to the negative impact it has on the living conditions and health of the most vulnerable population groups, especially considering prevailing inadequate levels of energy services in households [4]. For instance, according to Eurostat, in 2018, Portugal was the fifth country in the European Union where people could not afford to keep their homes adequately heated, with about 19% of the Portuguese population living in a situation of energy poverty, well above the European Union average of 7%. According to the published index, Bulgaria (34%), Lithuania (28%), Greece (23%) and Cyprus (22%) were the only countries that were labelled with worse classification than Portugal [5].

In 2019, the RAND Europe and VELUX Group published an edition of the Healthy Homes Barometer using datasets provided by European Union Statistics on Income and Living Conditions (EU-SILC) and Eurostat. The results from this report show that, based on four primary indicators for assessing living conditions—dampness, darkness, cold and excess noise—Portugal was labelled as the worst of the 28 EU countries recording a rate of one in two children living in an unhealthy home [6,7]. In the last decade, research has been conducted in Portugal to assess indoor environment conditions of homes of children and to identify indoor environmental quality-related health risk factors and opportunities for risk mitigation [8–11]. These initiatives have provided evidence on the existence of inadequate environmental conditions in homes, with levels of air quality indicators that do not comply with national and/or WHO guidelines. In particular, the existence of insufficient ventilation rates, as estimated based on CO_2 levels, have been reported consistently across studies [10–12]. Noteworthy, some of the dwellings that were targets of study presented also levels of air pollutants exceeding the national and/or WHO limit values, namely for particulate matter ($PM_{2.5}$ and PM_{10}) [10–12], volatile organic compounds (VOCs) [11,12], and airborne microorganisms (bacteria and fungi) [10,12,13]. The findings suggest that the indoor air quality (IAQ) in homes is affected not only by patterns and types of emissions that take place in the outdoor neighbouring areas (such as traffic-related pollution) but also by emissions occurring indoors from construction materials, household cleaning, personal care and other consumer products and other indoor activities (e.g., tobacco smoke). Recent research has also identified issues related to energy services as possible contributing factors to unhealthy environmental conditions in families with new-borns [8,11]. In fact, existing evidence at the national level [8,11] suggests that it is of utmost importance to implement effective measures that target both energy efficiency and non-energy benefits, such as reduced carbon emissions, reduced thermal stress, improved air quality, health and wellbeing.

Promoting behavioural changes has been increasingly considered a relevant approach for promoting energy savings and improved health [3,14]. However, efforts to improve energy efficiency often focus exclusively on energy impacts, while IAQ is addressed separately. To achieve energy-related benefits, actions can include investing in energy-efficient retrofits and renewable energy installations or in reducing consumption by efficient practices. To improve IAQ, healthy behaviours can be encouraged by providing information on the avoidable environmental risks (e.g., declared sources of pollution) and on strategies to dilute unavoidable indoor air pollutants (e.g., increasing ventilation). There are many possible practical applications, namely by increasing the amount and quality of relevant information to consumers in order to empower them to make efficient energy and healthy decisions.

Based on the information provided above, it is crucial to develop strategies that properly reflect the character, identity and needs of local homes and residents to effectively tackle the current energy, thermal comfort and IAQ problems. In particular, there is a research gap on developing regional assessments to establish actions to promote active citizen participation and achieve such multidisciplinary benefits [15,16]. This includes the need for identifying suitable opportunities to assist the citizens to be more motivated to change their behaviours and act as frontrunners to achieve healthy and energy-efficient homes and for evaluating the effectiveness of the derived actions in promoting beneficial behaviours. This study aims to comprehensively characterise a sample of 101 Portuguese families with children to identify evidence-based opportunities for designing actions and interventions that promote both long-term energy efficiency and health-promoting behavioural change related to IAQ. This work is the first part of an intervention study that aims to evaluate the changes in the behaviour of the 101 recruited families exposed to the nudging treatments designed based on the outcomes presented in this manuscript. The main hypotheses of this pre-intervention phase of the study are the following: (i) there is a substantial room for improving energy, comfort and health condition of the recruited Portuguese families, and (ii) the comprehensive analysis of the families and homes characteristics is useful to design evidence-based corrective measures to be included in a further intervention plan using the study population.

2. Materials and Methods

In order to test the hypotheses proposed for the study, a structured work plan including activities for the definition of eligibility criteria, recruitment of participants and data collection and analysis was designed. The procedures conducted are described as follows in detail.

2.1. Study Design and Participants' Recruitment

The framework designed for the NUDGE project (NUDging consumers towards enerGy Efficiency through behavioural science (https://www.nudgeproject.eu/, accessed on 3 November 2022) includes the execution of five demonstration studies conducted in Germany (DE), Greece (GR), Croatia (HR), Portugal (PT) and Belgium (BE) that intend to address multiple instances of consumer behaviour and test a set of behavioural interventions in scenarios with high potential for energy savings. In particular, the works that are being conducted in Portugal include a pilot study aiming at promoting long-lasting energy efficiency behaviour change in families, leveraged by the motivation for improvement of the health and comfort of young children. The present work was developed as part of the recruitment and preliminary data collection activities for having the participants fully engaged for the next steps of the NUDGE Portuguese pilot.

At the first stage of the works, a set of documentation, including the study protocol description, information to participants and informed consent, was concurrently prepared for requesting ethical approval. The ethics committee of the University of Porto approved the study and respective materials (Nr 114/CEUP/2021).

The works for recruitment started on July 2021, and the recruitment activities included: (i) a wide dissemination campaign namely through publications in the INEGI's newsletter, website, and social media accounts; (ii) email/phone contacts to families with young children that participated in a previous project with INEGI [11] and (iii) contacts at the main umbrella organisation for school parents' associations (National Federation of Parents' Associations (CONFAP)) and the Portuguese Consumer Defense Association (DECO), which has agreed to disseminate information related to the NUDGE pilot to reach a wider network of potential participants to the study. In order to be eligible to participate in this study, participants should meet all the following criteria: (i) to be a family with young children (from new-borns to up to 12 years of age at the time of the recruitment), (ii) to live in the district of Porto or nearby, (iii) to have Wi-Fi at home (iv) to not plan to move to a new home in the next 12 months and (v) to be properly aware of the study aims and provide a signed informed consent. The recruitment activities resulted in 101 eligible participants that provided consent to collaborate in the study, who were contacted for scheduling the visits for interview and building survey and smart electricity meters' installation works (for monitoring electricity consumption during the project execution). The home visits for interviews were conducted from July 2021 to April 2022.

2.2. Building Checklist and Data Collection

A user-friendly checklist was developed as a tool to ensure a uniform collection of the most relevant data on the energy use characteristics and on the putative nature of indoor air pollution in the participants' homes. Briefly, the selected contents of the checklist include structured sections to collect information on energy use, heating and ventilation systems and respective operating conditions, building characteristics, existence of declared indoor pollution sources (e.g., indoor smoking and air fresheners), building pathologies (e.g., moisture-related), cleaning procedures (routines and products) and characteristics of the surrounding outdoor environment. Features such as the user-friendliness of the checklist and reproducibility of the results were prioritised in the development of the tool. To harmonise the collection of data, the e-checklist was filled out by trained researcher(s) who interviewed the participants during the home visiting program. The English version of the checklist is available as an electronic-based tool at http://checklist.nudge.inegi.up.pt/, accessed on 3 November 2022, and access for NUDGE concept related implementations can be provided upon request by an email to nudge@inegi.up.pt. All the participants (n = 101) agreed to provide information for completing the checklist. During the visit to the participant homes, participants were also invited to send both gas and electricity invoices on a monthly basis to the email address of the team. The invoices that were received were analysed in order to collect information for a rough characterization of the total energy consumed and total costs of both electricity and gas use. Cost per kWh (EUR/kWh) was also estimated based on the total cost and used energy amount specified in the participants' invoices.

2.3. Questionnaire to Participants

After the home visits, participants were invited by email to complete an additional online questionnaire. This yielded a total of n = 86 questionnaire respondents, with 15 people not completing the form, out of the total sample of 101 participants. Although the questionnaire was very comprehensive, this article only presents data collected from a subset of questions related to socioeconomics, air quality and thermal comfort characteristics. Specifically, the questions used to gather information about the perceived air quality, income, thermal sensation within the home, thermal preference and thermal acceptability are presented in more detail below.

Monthly income was asked using multiple choice, with 9 options for answers (705 EUR or below, 706 EUR–1000 EUR, 1001 EUR–1410 EUR, 1411 EUR–2000 EUR, 2001 EUR–2500 EUR, 2501 EUR–3000 EUR, 3001 EUR–4000 EUR, 4001 EUR–5000 EUR, 5000 EUR or more), with the added option of giving no answer, or saying "I don't know". Income was subsequently transformed, with each option converted into the mid-point between the two anchors. Self-perceived socioeconomic status was measured by asking the participants to imagine a 9-step ladder where on the bottom, the first step, stand the poorest people, and on the highest step, the ninth, stand the rich. To assess perceived IAQ, the question "How do you judge the indoor air quality in your dwelling now?" was included providing a 9-item Likert scale ranging from extremely pleasant (1) to extremely unpleasant (9). Thermal sensation was measured by asking "How do you judge the indoor temperature?", offering 7 options for answering ranging from cold (1) to hot (7). Information on thermal preference and acceptability was collected by asking "At this moment, would you prefer to feel warmer, cooler, or no change?" and "At this moment, do you consider the thermal environment acceptable or not?", respectively.

2.4. Data Management and Statistical Analysis

Main data obtained from the checklist were presented through frequencies and valid percentages and/or, when applicable (for numeric data), mean and absolute minimum and maximum values. Briefly, percentage was calculated as following: $\% = (n \times 100)/N$, where n is the number of families who reported a given characteristic and N the total number of valid cases. For variables related to the building survey checklist, N corresponds the total number of participant families ($N_{home\ checklist} = 101$), excepting for one question: "Location of the dwelling within the building (floor)" that was only employed for families living in apartments (n = 64). For personal questionnaires, because answers were only successfully obtained for 86 participants, N used to calculate % was equal to the total number of respondents ($N_{questionnaires} = 86$). Electricity and gas data from January to June (consumption and costs), collected through the invoices, were also presented with the standard deviation and median. Statistical analysis was conducted using IBM SPSS Statistics, version 27, considering a statistical significance level of $p < 0.05$. Data normality was checked by the Kolmogorov–Smirnov test, and nonparametric tests were applied due to the skewed distribution of all metric variables. Significant variations in electricity and gas consumption and cost paid in the function of season, dwellings period of construction and number of occupants were checked with the Mann–Whitney *U* test. Correlations were tested using the Spearman method. Pearson's chi-square tests were used to search for associations between the prevalence of moisture-related problems and the existence of physical pathologies, as well as the existence of openable windows oriented to the north.

Nonparametric tests (Welch's *t*-test, Kruskal–Wallis rank sum test) were employed for statistical analysis on heating and air quality and their relationship to self-perceived economic status and income. The summary of statistical analyses that were conducted are presented in the Table S1 (please see the Supplementary Materials).

3. Results

All 101 families with children that agreed to participate in the study lived within a radius of 40 km from the city of Porto, in the northern region of Portugal. The approximate location of participant homes is presented in Supplementary Figure S1 (please see Figure S1 in the Supplementary Materials). A summary of the collected data on the characteristics of the homes is presented in Table 1, and the results are described in the following sections.

Table 1. Summary of the results collected through a checklist on the characteristics of the participants' homes.

Home Characteristics	n (%)	Mean (Min–Max)
Period of construction		
Before 1950	8 (8%)	
1950–1980	8 (8%)	
1980–2010	67 (66%)	
After 2010	18 (18%)	
Recent (last 6 months) refurbishing works	39 (39%)	
Dimensions of the dwelling (approximate)		
Floor area (m^2)		171.0 (62.0–680.0)
Mean ceiling height (m)		2.6 (2.4–3.4)
House Typology		
Apartment	64 (63%)	
Single-family house	37 (37%)	
Number of floors		
1	60 (59%)	
2	22 (22%)	
3	16 (16%)	
4	3 (3%)	
Location of the dwelling within the building (floor) *		
Ground floor *	7 (11%)	
1 *	10 (15%)	
2 *	18 (28%)	
3 *	14 (22%)	
4 or upper floors *	16 (25%)	
Occupancy patterns		
Number of occupants of the house		4 (2–7)
Babies (0–4 years old)	66 (65%)	1 (1–2)
Children/adolescents (5–17 years old)	62 (61%)	2 (1–3)
Adults (18–65 years old)	101 (100%)	2 (1–5)
Seniors (>65 years old)	3 (3%)	1 (1–2)
Period living in this dwelling		
<2 years	19 (19%)	
2–5 years	46 (46%)	
6–10 years	17 (17%)	
>10 years	19 (19%)	

Table 1. *Cont.*

Energy supply systems and equipment	
For home environment and water heating	
Electricity	77 (76%)
Natural gas	68 (67%)
Bottle gas (propane/butane)	17 (17%)
Solar Photovoltaic energy	4 (4%)
Solar Thermal energy	18 (18%)
Wood (logs or chips)	32 (32%)
Pellets	6 (6%)
District Heating	0 (0%)
Other	2 (2%)
None	0 (0%)
For cooling	
Electricity	36 (36%)
Solar photovoltaic energy	4 (4%)
Other	0 (0%)
None	65 (64%)
For cooking	
Electricity	100 (99%)
Natural gas	17 (17%)
Bottle gas (propane/butane)	6 (6%)
Solar Photovoltaic energy	4 (4%)
Wood (logs or chips)	1 (1%)
Pellets	0 (0%)
Other	1 (1%)
None	0 (0%)
Electricity switchboard	
Single-phase	90 (89%)
Three-phase	11 (11%)
Electricity tariff	
Simple	88 (87%)
Bi-hourly	12 (12%)
Tri-hourly	1 (1%)
Equipment and other appliances	
Heating, ventilation/acclimatization devices	
Electric heating appliances	
Air conditioner(s)	26 (26%)
Portable electric heater	32 (32%)
Space Radiators	13 (13%)
Central heating	42 (42%)
Radiant/heated floor	4 (4%)
Humidifiers	2 (2%)
Dehumidifiers	25 (25%)
Combustion devices	
Open Fireplace	7 (7%)
Modern Fireplace (closed)	28 (28%)
Heating stove	4 (4%)
Portable gas heater	15 (15%)
Fan heater	32 (32%)
Fan	10 (10%)
Air purifier(s)	2 (2%)
Other	1 (1%)
None	4 (4%)
Water heating appliances	
Gas water heater (boilers)	73 (72%)
Heat pump	8 (8%)
Electrical heaters	20 (20%)
Solar water heaters	18 (18%)
Other	0 (0%)

Table 1. *Cont.*

Cooking Devices		
Gas stove	22 (22%)	
Electric stove	100 (99%)	
Wood stove	1 (1%)	
Other	3 (3%)	
Home EV charging point	8 (8%)	
Set points for temperature		
For domestic hot water		
Cold season (°C)	38 (38%)	54 (39–70)
Warm season (°C)	37 (37%)	51 (37–65)
For indoor environment		
Cold season (°C)	27 (27%)	21 (18–25)
Warm season (°C)	8 (8%)	21 (17–24)
Factors with putative impact on air quality		
Consumer Products—Indoor use		
Air freshener and other fragranced products	74 (73%)	
Manual	37 (37%)	
Continuous/Automatic	31 (31%)	
Incense	22 (22%)	
Scented candles	23 (23%)	
None	27 (27%)	
Pesticides/Insecticides	32 (32%)	
Manual insecticides	15 (15%)	
Automatic aerosol insecticides	20 (20%)	
Cockroach pesticide	0 (0%)	
Rats control products	0 (0%)	
Other	3 (3%)	
None	69 (68%)	
Cleaning products and procedures		
Bleach or detergent with bleach	89 (88%)	
Spray	25 (25%)	
Liquid	80 (79%)	
Frequency (times per week)		1.8 (0.3–7.0)
Detergent with ammonia	28 (28%)	
Spray	4 (4%)	
Liquid	26 (26%)	
Frequency (times per week)		1.5 (0.3–7.0)
Other detergent/cleaning products	99 (98%)	
Spray	77 (76%)	
Liquid	90 (89%)	
Frequency (times per week)		1.8 (0.3–7.0)
Wax/Furniture polish	4 (4%)	
Spray	2 (2%)	
Liquid	3 (3%)	
Frequency (times per week)		0.7 (0.5–1.0)
Indoors pets	50 (50%)	
Dog	33 (33%)	
Cat	20 (20%)	
Other	7 (7%)	
Plants inside the house	61 (60%)	
Current practice to smoke indoors	6 (6%)	
Cigar/cigarettes	3 (3%)	
Electronic cigarettes	4 (4%)	
Signs of indoor pathologies		
Physical	24 (24%)	
Moisture-related	39 (39%)	

Table 1. *Cont.*

Fenestration/Windows		
Window orientation		
North	52 (51%)	3.6 (1.0–8.0)
West	56 (55%)	3.6 (1.0–11.0)
South	62 (61%)	3.3 (1.0–9.0)
East	58 (57%)	3.4 (1.0–9.0)
Solar shading		
Both internal and external	51 (50%)	
Only internal	34 (34%)	
Only external	15 (15%)	
None	1 (1%)	
Opening windows	101 (100%)	
Before 7 a.m.	0 (0%)	
7–10 a.m.	73 (72%)	
10–12 a.m.	56 (55%)	
12–17 p.m.	57 (56%)	
17–20 p.m.	36 (36%)	
after 20 p.m.	0 (0%)	
Opening windows during cleaning procedures		
Always	73 (72%)	
Often	21 (21%)	
Sometimes	6 (6%)	
Never	1 (1%)	
Surrounding outdoor sources (up to 100 m)		
Traffic-related	62 (61%)	
Busy road	44 (44%)	
Highway	4 (4%)	
Car parking	8 (8%)	
Gas stations	7 (7%)	
Other	34 (34%)	
Industrial-related	4 (4%)	
Agricultural-related	42 (42%)	
Animal husbandry	14 (14%)	
Cultivated fields	40 (40%)	
Commercial	75 (74%)	
Laundry	12 (12%)	
Coffee bar/ Restaurant	64 (63%)	
Other commercial	45 (45%)	
Green/Forested area (up to 100 m)	51 (50%)	

n refers to the number of respondent families who presented the referred characteristic, and (%) refers to respective percentage in the total number valid cases (N). The number of valid cases used for calculating the % corresponds to the total number of participant families (N = 101), excepting for the variables marked by an asterisk (*). * Only applicable to apartments (N = 64); thus, the total valid cases used for the calculation of the prevalence of the marked characteristics was 64. EV, Electric vehicle; Max, maximum; Min, minimum.

3.1. General Building Characteristics and Occupants

More than half of the participant families lived in buildings constructed between 1980 and 2010 (n = 67; 66%), with about 16% living in buildings older than 1980 and 18% in buildings completed after 2010. Nevertheless, recent—related to the last 6 months—renovation and/or refurbishing works were conducted in a substantial number of homes (n = 39; 39%).

According to the data from Eurostat, in 2020, the percentage of people living in flats in Portugal was similar to the average value reported for the EU population (46%) [17]. For the sample of families considered in this study, a substantially greater percentage was obtained (n = 64; 63%). This is likely to result from the fact that this study covers a limited geographical area (that has a relatively high share of urban areas and includes an important urban area of the country, the city of Porto) and a very specific population group (families with children younger than 12 years old).

The average area and ceiling height of the dwelling was 171.0 m^2 and 2.6 m, respectively. Considering the number of occupants, the density of occupancy (person/m^2) varied from 0.01 to 0.06 (Mean: 0.03). The number of children (<17 years old) per family ranged from 1 to 4 (Mean: 2). Most of the families lived in the surveyed dwelling for more than 2 years.

3.2. Energy Use by the Participant Homes

Data from both checklist and energy invoices were analysed to characterise the current use of energy by the families, and the obtained results are presented in Sections 3.2.1 and 3.2.2, respectively. In particular, data from the checklist were used to identify the energy sources and existing equipment existing in the homes, devoting especial attention to the appliances used for water and indoor environment heating and cooking purposes. In turn, electricity and gas invoices were studied for obtaining data on the consumption and related costs.

3.2.1. Energy Vectors and Specific Equipment

According to the data collected, electricity is the main energy vector used for space and/or water heating (n = 77; 76%), followed by natural gas (n = 68; 67%) and wood (logs or chips) (n = 32; 32%). Forty-four percent of the participants used both electricity and natural gas for space and water heating purposes. A very small percentage of families reported to use solar photovoltaic (PV) energy (n = 4; 4%) as a complement to the use of electricity from the national grid. However, a higher percentage (n = 18; 18%) presented solar thermal energy as an energy vector to suppress space and water heating needs. Bottled gas (propane/butane) (n = 17; 17%) and pellets (n = 6; 6%) were the other vectors represented in the homes included. Data from the checklist also found that district heating networks were not used as a solution for any of the participant homes. This is a demonstration of the current national structure for space and water heating that includes a residual amount of practical cases of district heating/cooling networks, as opposed to other European countries, such as Denmark or Sweden, that have above 45% of the heat delivered to buildings coming from district heating [18].

For cooking, electricity (n = 100; 99%) was used in almost every home in the study, with natural gas (n = 17; 17%) and bottled gas (propane/butane) (n = 6; 6%) being the other energy vectors reported. In one of the homes, equipment consuming wood (logs or chips) was also used for cooking.

The checklist employed in this study allowed also collecting information on the main type of devices/appliances that were used by the participant families. Forty-two percent of the participant's homes were equipped with a central heating system. The electric space heating appliances used by participants included portable electric heaters (n = 32; 32%), air conditioners (n = 26; 26%), space radiators (n = 13; 13%) and radiant/heated floors (n = 4; 4%). Some of the houses also included combustion devices such as a modern closed fireplace (n = 28; 28%), portable gas heater (n = 15; 15%), open fireplace (n = 7; 7%) and heating stove (n = 4; 4%). For space cooling purposes, air conditioners (n = 26; 26%), and fans (n = 10; 10%) were the electrical appliances used among the respondents. Additionally, a small number of participants (n = 4; 4%) reported to have no equipment for heating, ventilation and acclimatisation. Furthermore, about one-fourth of the homes were equipped with dehumidifiers (n = 25; 25%), although the use of humidifiers was much lower (n = 2; 2%).

Regarding equipment used for domestic hot water preparation, the most common system was a gas water heater (boilers) (n = 73; 72%), followed by electrical water heaters (n = 20; 20%), solar water heaters (n = 18; 18%) and heat pump (n = 8; 8%).

In addition, some of the participants reported having a home electric vehicle (EV) charging point (n = 8; 8%).

3.2.2. Preliminary Data on Natural Gas and Electricity Consumption and Costs

Although the delivery of the natural gas and electricity invoices on a monthly basis was requested from all participants, the rate of participation was lower than expected. It was noted that the months with the higher percentage of participants who provided invoices were the first four months of the year, ranging from 45 to 51% of all participants who pay for electricity (n total = 101) and from 32 to 41% for natural gas invoices (n total = 71). Despite the reminders from the research team, the rate of participants that sent invoices appeared to decrease throughout the months, suggesting a degree of participant "fatigue" effect for recurrent tasks without associated incentives. It is thus important to disclose that the data presented in this section should be carefully interpreted, since the analysis was based on an inconstant (and low) number of engaged participants that provided their invoices.

Data on electricity consumption and costs from January to June of 2022 acquired from the invoices are presented in Table 2.

Table 2. Summary of the results collected through the participants' electricity invoices.

Month	n (%)	Electricity Consumption (kWh)		Total Cost (EUR)		Cost per kWh (EUR/kWh)	
		Mean ± SD	Min–Max	Mean ± SD	Min–Max	Mean ± SD	Min–Max
January	52 (51)	443 ± 309	92–1394	87.13 ± 58.72	22.96–289.69	0.155 ± 0.016	0.120–0.199
February	45 (45)	420 ± 313	113–1647	84.58 ± 52.58	29.99–257.29	0.157 ± 0.017	0.119–0.199
March	50 (50)	383 ± 285	109–1576	80.60 ± 54.51	29.74–270.57	0.158 ± 0.014	0.119–0.193
April	45 (45)	317 ± 212	58–1161	69.66 ± 50.74	5.05–290.01	0.158 ± 0.016	0.124–0.202
May	32 (32)	282 ± 202	53–1006	66.33 ± 45.46	23.23–204.65	0.166 ± 0.034	0.124–0.341
June	26 (26)	321 ± 234	113–1137	72.04 ± 44.34	32.16–224.35	0.161 ± 0.014	0.124–0.202

n (%) refers to the total number of families that sent gas invoices and the respective percentages in the valid cases (participants with electricity, N = 101). Max, maximum; Min, minimum; SD, standard deviation.

The average monthly consumption values ranged from 282 kWh (amount paid 66.33 EUR) in May to 443 kWh (amount paid 87.13 EUR), which was registered in January (Table 2) for electricity and from 176 kWh (amount paid 18.11 EUR) in June to 724 kWh (amount paid 54.98 EUR) in January for gas. In addition, the total electricity consumption and respective costs seemed to be very similar for the first 3 months of the year; however, for natural gas consumption, a substantially higher consumption was observed in January (average value of 724 kWh) in comparison to the following months (Table 3). In fact, the variation of the overall electricity and gas consumption by the users followed the same pattern throughout the period of study, presenting values that were significantly higher in the heating (January–March) than non-heating season months (electricity: $U = 1235.0$, $z = -2.589$, $p = 0.009$; gas: $U = 298.0$, $z = -3.474$, $p < 0.001$). In terms of total cost paid, costs with gas were significantly higher in the heating season months than in the non-heating season ($U = 319.0$, $z = -3.220$, $p = 0.001$).

Table 3. Summary of the results collected through the participants' gas invoices.

Month	n (%)	Gas Consumption (kWh)		Total Cost (EUR)		Cost per kWh (EUR/kWh)	
		Mean ± SD	Min–Max	Mean ± SD	Min–Max	Mean ± SD	Min–Max
January	29 (41)	724 ± 628	93–2651	54.98 ± 43.23	6.74–174.35	0.063 ± 0.011	0.049–0.091
February	23 (32)	398 ± 333	91–1225	34.06 ± 25.45	7.35–91.68	0.068 ± 0.011	0.049–0.091
March	29 (41)	397 ± 274	46–1052	34.68 ± 26.94	4.94–120.96	0.068 ± 0.011	0.049–0.091
April	29 (41)	305 ± 233	23–737	25.24 ± 15.11	5.67–64.87	0.068 ± 0.012	0.049–0.091
May	21 (30)	235 ± 176	11–595	23.30 ± 18.48	1.68–70.98	0.066 ± 0.011	0.051–0.091
June	15 (21)	176 ± 168	11–656	18.11 ± 15.38	1.65–63.18	0.069 ± 0.014	0.051–0.091

n (%) refers to the total number of families that sent gas invoices and the respective percentages in the valid cases (participants using gas, N = 71). Max, maximum; Min, minimum; SD, standard deviation.

Statistical analysis of the data from energy invoices and data from the checklist showed the existence of significant associations between both electricity and gas total consumption and the dimension (area) of the houses ($r_s = 0.366$, $p = 0.002$; $r_s = 0.405$, $p = 0.008$, respectively). In addition, homes built before 1980 (16 out of 101) presented electricity consumption and total costs significantly greater than those reported for more recent dwellings

($U = 179.0$, $z = -3.0.42$, $p = 0.002$; $U = 146.0$, $z = -3.518$, $p < 0.001$). Similar results were obtained for single-family houses, i.e., families living in single-family houses registered significantly higher levels of electricity consumption and total costs than families living in flats ($U = 385.0$, $z = -2.697$, $p = 0.007$; $U = 319.0$, $z = -3.451$, $p < 0.001$). Nevertheless, no significant association was found between consumption and the number of occupants or children living in the house. Furthermore, houses with a window oriented north (51 out of 101) presented a significantly higher consumption of electricity ($U = 387.5$; $z = -2.789$, $p = 0.005$; $U = 131.0$ $z = -2.211$, $p = 0.027$). For instance, a higher number of windows along the north façade was also associated with an increased consumption of electricity and gas ($r_s = 0.296$, $p = 0.012$; $r_s = 0.349$, $p = 0.024$).

3.3. Control on Thermal Comfort

According to the data collected, only 42% of the participant homes had a central heating system, but only 27% of the participants reported to have an active thermostat to control the operation of the system. For those participants, the temperature set points defined in the thermostats varied from 18 to 25 °C during the heating season. It was also observed that a large majority of the families did not have any device for cooling the indoor environment (n = 65; 64%). Nevertheless, all the buildings (excepting one) were equipped with adjustable shading components in the glazed façades. The most common situation was that homes had external shading (65%). About half of the participant homes had both internal and external shading, and 34% only had internal shading.

3.4. Putative Sources of Air Pollutants Identified in the Participant Homes

The data collected through the checklist allowed identifying the prevalence of the existence of putative sources of air pollution and other factors that may influence IAQ in the participant homes. In particular, it was observed that a great percentage of the families enrolled in the study (73%) used air fresheners and/or other fragranced products as incense and aromatic candles. Among these, 31 families used automatic air fresheners continuously dispensing fragranced aerosols to the indoor environment, and the remaining used manual options in specific situations. This study showed that 22 families used incense and 23 utilised scented candles, whereas 8 out of these families reported to use both. In addition, 32% reported using manual (n = 15; 15%) and/or automatic aerosol insecticides (n = 20; 20%) indoors. Related to the house cleaning procedures, most families employed a variety of products, including bleach or detergent with bleach (n = 89; 88%), about 1.8 times per week. Some of our participants (n = 28; 28%) also reported using detergents with ammonia about 1.5 times per week. Nonetheless, almost all (n = 99; 98%) of the families surveyed used other type of detergent/cleaning products about 1.8 times per week. Only 72% of the participants reported to always open the windows during their cleaning practices.

Among the homes surveyed, 39% presented signs of moisture-related (dampness and/or mould) damages in the internal surfaces (walls and/or ceilings). Findings from this work also found that homes with openable windows oriented to the north presented a greater prevalence of signs of dampness (25 out of 51, 49%) than the dwellings that did not have this characteristic (13 out of 50, 26%) ($\chi^2 = 5.70$, $p = 0.024$). Some of the dwellings presented signals of physical pathologies (24%, noticeable cracks, fissures, altered staining or peeling), and this set of dwellings was found to present a higher prevalence of dampness-related pathologies (17 out of 24, 71%) than the houses that did not have any signal of physical pathology (21 out of 77, 27%) ($\chi^2 = 14.79$, $p < 0.001$).

A variety of outdoor sources of air pollution was identified in the surrounding environment of the homes. A substantial number of participants live in areas nearby traffic-related sources (n = 62; 61%), such as busy roads (44%). Since the recruitment for the study was opened to cover homes located in urban, suburban and rural or semi-rural areas, it was found that a substantial number of families live nearby sources of pollution characteristic of commercial areas (n = 75; 74%), mainly coffee bars and restaurants (n = 64; 63%) and/or of agricultural-related activities (n = 42; 42%), such as cultivated fields and farms with animal husbandry. A small percentage of the houses are located in areas with industrial activities (n = 4; 4%).

3.5. Questionnaire Data

In addition to the home-specific data reported above, as part of this study, an online questionnaire was also administered for collecting participant-specific information focusing on sociodemographic characteristics, thermal comfort related questions and perceptions of air quality. Table 4 contains an overview of all the results.

Table 4. Socioeconomic, thermal preference and indoor air quality status.

Participant Families Characteristics	n (%)	Mean (Min–Max)
Income		
706 EUR–1000 EUR	2 (2.4%)	
1001 EUR–1410 EUR	5 (6.0%)	
1411 EUR–2000 EUR	23 (28%)	
2001 EUR–2500 EUR	13 (16%)	
2501 EUR–3000 EUR	14 (17%)	
3001 EUR–4000 EUR	15 (18%)	
4001 EUR–5000 EUR	7 (8.4%)	
Above 5000 EUR	4 (4.8%)	
Unknown	3	
Average calculated income		2251 (853–5500)
Self-perceived socioeconomic status		4.3 (2–7)
Indoor air quality		
Indoor air quality perception		3.7 (1–6)
Perceived indoor air quality		
Extremely pleasant	1 (1.2%)	
Very pleasant	8 (9.3%)	
Pleasant	35 (41%)	
Neutral	22 (26%)	
Unpleasant	15 (17%)	
Very unpleasant	5 (5.8%)	
Thermal sensation		
Cool	3 (3.5%)	
Slightly cool	20 (23%)	
Neutral	43 (50%)	
Warm	20 (23%)	
Thermal preference and energy consciousness		
Thermal preference		
Warmer	36 (42%)	
No change	50 (58%)	
Thermal acceptability		
Acceptable	83 (97%)	
Not acceptable	3 (3.5%)	
Reason to ventilate		
To adapt the indoor temperature	12 (14%)	
To remove stuffiness	39 (45%)	
To dilute air pollutants	23 (27%)	
Other	12 (14%)	
Self-perceived energy consciousness		6.3 (3–9)

n refers to the number of respondent families who presented the referred characteristics, and (%) refers to respective percentages in the total number valid cases. The number of valid cases used for calculating the % corresponds to the total number of participant families who answered to the questionnaire (86). Max, maximum; Min, minimum.

The self-perceived economic status averaged 4.31 (SD = 1.79), while the average monthly income was 2251 EUR. Since the lack of central heating has been considered one of the indicators used to estimate energy poverty, the existence of an association between families' income and the existence of central heating was tested, but no statistical differences were found (Welch's *t*-test, $t = -1.40$, $p = 0.17$). Interestingly, by contrast, statistically significant differences were denoted between the self-perceived economic status and the presence of central heating (Welch's *t*-test, $t = -3.62$; $p < 0.01$), with persons who own central heating placing themselves higher on the socioeconomic ladder.

Regarding the perceived IAQ, although a substantial number of participants noted that the air quality was pleasant (41%) or neutral (26%), some of the participants qualified home's IAQ as unpleasant (17%) or very unpleasant (5.8%). No statistically significant relationship was found between self-perceived air quality and self-perceived economic status (Kendall[s tau test, $\tau = -0.05$, $p = 0.61$) or monthly income (Kendall's tau test, $\tau = -0.01$, $p = 0.88$).

Further, most of the respondent families reported to be neutral regarding their thermal sensation at home, with 23% noting that they feel warm, 23% slightly cool and 3.5% cool. Regarding thermal preferences, it was found that 58% of the participants did not feel the need for any change, but 42% would like to feel warmer at home.

The most common motivation to ventilate an indoor environment was to remove air stuffiness (45%), and the dilution of air pollutants was presented in 27% of the respondent families. A further 14% reported using ventilation as a way to adapt the air temperature, while another 14% referred to opening the windows for other reasons.

We also questioned participants about their perceived energy consciousness, providing a 9-step ladder on which they can place themselves. A majority scored themselves with a 6, at an average of 6.27. For instance, in general, data from the questionnaire demonstrated that there was room for improving the level of awareness of the families on the best practices to encourage energy-efficient and healthy behavioural changes.

4. Discussion

This study collected comprehensive information on a wide range of aspects, including building and equipment features, energy use and potential sources and determinants of IAQ and health, for a sample of 101 Portuguese families with children and their homes. The collected data can be used to gain a better understanding of the current living conditions of these families and to develop evidence-based recommendations for improvement. In particular, this section aims to critically analyse the findings to explore the answers to the research questions defined to the study and, in particular, to inform the design of relevant interventions for the upcoming phases of the NUDGE project research.

4.1. Determining Factors of Electricity and Gas Consumption

The data collected from the energy bills of the study participants showed that there is a significant seasonal influence on both electricity and gas consumption, which is likely to be influenced by climate-related factors. For example, the second trimester of the year saw a significant decrease of energy use, which corresponds to the beginning of the warm season with increased outdoor temperatures and reduced need for heating systems. Additionally, due to these climatic factors, families tend to spend more time indoors during the heating season. This suggests that the heating season may be a particularly opportune time to promote energy-efficient practices among families. Furthermore, families living in single-family houses presented significantly higher levels of electricity consumption than those living in apartments. This is consistent with findings from other European countries, such as the studies by Brounen et al. and McLoughlin et al. that found energy consumption is substantially lower in apartments compared to semidetached and detached Dutch [19] and Irish family houses [20]. The authors suggested that this might be related to smaller number of occupants in apartments. Nevertheless, although some research studies conducted worldwide have reported the link between the number of family members and the electricity consumption [21], this study found no significant association between consumption and number of occupants (or children) living in the house. Other building aspects, such as the number of windows facing north, were found to be associated with significant increase in electricity and gas consumption. This is likely due to increased heating needs resulting from cold winter winds generally coming from the north and low solar gains.

The observation that a small percentage of the participants report the use of cleaner energy sources, such as solar, alongside with a high share that use wood for heating purposes (32%), suggests that actions focusing on fuel switching and educational campaigns to promote the use of more efficient heating technologies could be valuable to reduce to increase energy savings and mitigate environmental hazards.

4.2. Existing Options for Controlling Thermal Comfort

The lack of central heating has been considered one of the indicators of energy poverty among EU countries [22]. According to the World Health Organization (WHO), to achieve an adequate standard of warmth in homes, temperatures of 21 °C in living rooms and 18 °C in other occupied rooms should be maintained [23]. Among the participants in this study who use thermostats to control indoor temperature, the reported temperature set points varied from 18 to 25 °C during the heating season, with seven participants reporting their thermostats set at target temperatures above 21 °C. Based on these observations, promoting energy savings through recommendations to reduce indoor temperature set points may have limited effectiveness due to the small share of participants that would be able to implement it (only 28 out of 101).

Recent data from the EU-SILC survey show that 7.4% of the EU population in 2020 was unable to keep their home adequately warm [24]. This percentage is higher in some EU countries, such as Portugal, where 17.5% of the population face similar issues [25]. In a recent study, conducted in the metropolitan area of Porto, 30% of homes of families with infant twins were found to have indoor temperatures lower than 18 °C during the cold season [11]. It should be noted, though, that the ability to keep a home adequately warm depends on several factors, including the general condition of the building, the outside temperature, the cost of energy and the socioeconomic status of the people. All these factors need to be properly explored to derive effective policies to help the most vulnerable Portuguese families in achieving adequate levels of thermal comfort in their homes.

The climate in Porto is temperate oceanic, characterized by mild, rainy winters and pleasantly warm, dry sunny summers. Due to these climate characteristics, the need for heating homes in the winter is greater than the need for cooling in summer. This also likely explains why most participant families do not have any cooling systems. However, despite being underexplored, overheating can occur during the summer and further research is needed to address this issue and identify strategies to prevent it. In fact, data on average cooling degree days from 1979–2021 show that Portugal has the sixth-highest needs for cooling among EU countries [26]. External shading devices have been found to be an effective solution in reducing cooling loads and the risk of overheating by intercepting and reducing incident solar radiation before it passes through the glass panes [27]. In agreement, this study found that 65% of the homes had external shading devices.

4.3. Opportunities for Mitigating Air Pollution

Source control is considered the most efficient strategy for controlling IAQ, supporting ventilation, by reducing the primary exposures to indoor-generated pollution [28]. This refers to strategies that aim to prevent or limit the pollutant emissions in the built environment. Identifying opportunities to implement a source control-based approach is essential, and it is important to be aware of the existence of avoidable sources in buildings. In line with this, this study collected information on sources that may exist in homes, mainly those that have the potential to be managed by changes in the occupant behaviour and choices that can be incorporated in a joint approach to boost energy-efficient and healthy air-promoting behaviours among the local families.

A variety of consumer products that are part of the daily routine of families, including cleaning products, air fresheners and insecticides, can substantially impair the air quality and increase risk of hazardous exposures at home [11,29,30]. The exposure to fragranced products, in particular, has been associated with the development of a wide range of health problems, including respiratory constraints, mucosal symptoms, headaches, dermatological effects, asthma attacks and neurological problems [30]. This study found that 73% of families reported to using air fresheners and/or other fragranced products, such as incense and aromatic candles, and 88% reported using cleaning products such as bleach or detergent with bleach about 1.8 times per week. This percentage is higher than the observed in similar recent studies conducted among Portuguese families with new-born children (78%) [8], and in Spain (72%, n = 1945) among parents of pupils aged 6–12 years [31]. However, since the survey was conducted during the COVID-19 pandemic outbreak, it is worth noting that the observation may be related to the possible increasing trend in use of cleaning agents with disinfection properties, motivated by the pandemic situation.

Since all the products mentioned in this subsection may constitute the source of several hazardous substances to the indoor environment, it is crucial to use these products carefully. It is important to only use the cleaning products as needed and to ensure proper ventilation of indoor spaces to avoid risks to health.

Excessive condensation caused by thermal insulation gaps, excess moisture, or dampness can lead to wet surfaces and materials, which can result in signs of building-related issues such as mould growth, damp stains, water damage, condensation on windows and musty odours [30]. Studies have shown that the presence of mould and dampness seems to correlate well with increased risk of allergic symptoms and respiratory health issues, including asthma, which may result in an increased number of sick days [32–35]. Out of the homes surveyed, 39% showed signs of damage caused by moisture, such as dampness and mould, on their internal surfaces. This prevalence is higher compared to other European countries such as the Netherlands (15%), Belgium (20% in social housing), Germany (30%) and the UK (20–25%) [36] and also higher than a recent study of 309 families with new-born children (24%) conducted in Porto [8]. These types of building pathologies typically occur due to structural problems in the building envelope or specific materials, insufficient ventilation and difficulty maintaining adequate indoor temperatures in the winter.

Using air conditioning or dehumidifiers to control moisture is considered an effective and user-friendly approach, but it may consume significant amounts of energy. However, in our study, the incidence of moisture-related problems was not found to be significantly associated with the use of dehumidifiers or air conditioners. The WHO guidelines for dampness and mould in indoor environments recommend strategies for controlling moisture, for dampness and mould mitigation, such as addressing the proper control of indoor air temperature and humidity, and of ventilation/air circulation conditions [34]. Additionally, this work found that homes with openable windows facing north had a higher prevalence of signs of dampness, in addition to higher energy consumption. This suggests that families living in homes with north-facing windows may benefit from being informed about remedial strategies to mitigate the appearance and spread of dampness-related problems.

It is essential to also identify the sources of air pollution at the neighbourhood level as hazardous pollutants, such as particulate matter resulting from emissions from traffic, commercial, agricultural and industrial sources that can penetrate the building envelope and impact air quality. By understanding the location and typical patterns of outdoor pollution sources, it is possible to design and improve ventilation practices on a case-by-case basis. These practices may include recommendation to open windows that are sheltered from pollution sources, taking into account the local wind patterns, and to open windows during periods when the pollution sources are less active (e.g., avoiding rush hour traffic).

4.4. Exploring the Potential of Improving Natural Ventilation

Ensuring adequate ventilation levels by replacing contaminated indoor air with “clean” outdoor air is of utmost importance in diluting indoor air pollutant concentrations. Recently, ventilation has been recognized also as a first preventive measure to manage the risk of transmission of airborne diseases, such as COVID-19, in enclosed spaces [37]. Additionally, cross-ventilation has been recommended as an effective approach in renovating the air. The survey conducted in this study showed that the majority of the homes have windows in more than one facade with different orientations. This can be used to promote cross-ventilation and/or to choose to open the window(s) that are more sheltered from outdoor air pollution sources. In homes, window opening is the most common and preferred method for occupants to control the IAQ [38]. Passive ventilation through the wise control of the window opening can be used by occupants to reduce the air stuffiness inside homes, mitigate the risk of exposure to indoor pollutants and to save energy. In this study, 72% of families reported to consistently open the windows during cleaning procedures. It is important though to recommend ventilating during and after the pollutant emitting procedures, such as cleaning and activities that use declared pollution sources (e.g., painting or other events using varnishes/ paints) to remove chemicals and promote healthy indoor air in homes.

The population under study reported the morning period from 7 to 10 a.m. as the preferred time of day to open windows. This schedule coincides with the typical morning periods of high traffic, during which the ambient levels of pollutants such as particulate matter and NO_2 can be particularly high. Previous studies have found that the practice of opening windows at home is activity and time-dependent, but can also be influenced by other factors, including outdoor temperature, relative humidity, wind speed and airborne particle concentration [39,40]. In the recent decades, attempts to make dwellings airtight to reduce energy consumption for heating may have led to buildings with lower ventilation rates and, consequently, to potentiating the accumulation of hazardous indoor contaminants and impaired IAQ. However, the promotion of natural ventilation can also be explored to promote energy-saving behaviours. For regions with temperate climates, such as Porto, the use of natural ventilation can meet most thermal comfort requirements for a significant portion of the year. Thus, promoting practices of opening windows in the periods of higher or lower ambient temperatures are expected in cold and warm seasons, respectively, might have a three-fold beneficial effect: promoting air quality, thermal comfort and energy savings (by reducing heating/cooling needs).

A growing body of evidence has shown the potential of using Internet of Things (IoT) systems to monitor environmental parameters such as CO_2 and temperature and triggering warnings to occupants, for example, when it is necessary to open windows due to high levels of CO_2 [41]. In the context of the pandemic, the effectiveness of this technological approach has been particularly demonstrated in reducing the risk of severe acute respiratory syndrome coronavirus (SARS-CoV-2) transmission by ensuring the introduction of an adequate amount of fresh air to avoid the accumulation of infected aerosols in indoor settings [42]. Additionally, there is evidence of the use of technological solutions that allow for real-time monitoring and collecting direct feedback on energy consumption. This approach has a high potential to reduce electricity consumption in a clear and engaging way [43].

5. Study Limitations

This study was designed to obtain a comprehensive characterization of the 101 Portuguese families, which will be further exposed to an intervention plan aiming at achieving improved energy saving and healthy behaviours. However, some limitations related to the characteristics of the study design, need to be properly disclosed and taken into consideration. Specifically, the limited sample size (n = 101) does not allow for robust extrapolation of the results to the general population group of families with children in the region. Further, the sample size varied across the components of the study, namely between datasets from building survey checklist (N = 101), personal questionnaire (N = 86) and energy bills (varied across the months of study). The results from the statistical analysis exploring associations between checklist and questionnaire or invoices variables should be carefully interpreted due to the existence of missing questionnaire data for some of the 101 participants, and this may compromise the representativeness of the data presented. Therefore, increasing the sample size in future investigations would minimize the risk of bias in the reported data and increase the robustness of the results. Additionally, while the global energy prices have risen sharply in Europe, primarily as a result of the invasion of Ukraine [44], the data collected from the electricity and gas invoices of participant homes show a median increase of 4% in the price of electricity occurred in May, with no robust evidence of a substantial increase in natural gas. However, due to the announced increase in prices for the near future, it is important to control the situation throughout the time and monitor the respective impacts. This study also collected information on relevant characteristics of the living built environment. However, some variables that can have impact on energy consumption and thermal comfort (quality of insulation, shape factor of building, efficiency of the existing equipment, etc.) and objective assessments (monitoring energy consumption for specific equipment, operative temperature, etc.) were underexplored and should be considered in the future studies to allow broader analyses. As an example, a combined analysis of the operative temperature, resulting from a weighted average of air and mean radiant temperature, with the existing insulation level and the shape factor of the building unit can be of utmost importance to objectively characterize the thermal comfort of dwellings.

6. Conclusions and Further Work

This study is part of a joint research project that combines the fields of health, energy and behavioural science to improve the quality of existing data on the Portuguese housing characteristics. The research provided valuable insights that enabled the establishment of strategies and guidance of further research to optimise energy efficiency and to ensure healthy environmental conditions in homes.

The findings suggest that, in addition to policies aiming at addressing energy poverty in Portugal, the heating season and approaches used for indoor environment and water heating should be particularly explored for promoting energy-efficient and healthy practices among families. Specifically, the study recommends considering measures that promote the replacement of low energy-efficient and high emission sources used for heating purposes, such as wood, which is currently used by more than one-fourth of the participants, with technologies that use cleaner energy sources such as photovoltaics.

The study also suggests exploring the potential for introducing recommendations for reducing indoor temperature set points during the heating season to promote energy savings. However, currently, there is a limited potential of effectiveness, as most of the Portuguese families do not have a heating system controlled by a thermostat.

Finally, the study emphasizes the importance of setting up public awareness campaigns to increase the population's level of literacy on the hazardous effects of air pollution and on the panel of pollutant sources that can be inadvertently introduced into homes. Specifically, informing families about strategies that promote the conscious use of consumer products, such as cleaning products, air fresheners and insecticides, by careful adjustment of the product use to the needs, alongside ensuring the proper ventilation of indoor spaces and recommendations on dampness and mould mitigation, can have a major impact on preventing health-related environmental risks. Moreover, providing guidance to families on strategies based on the wise control of window opening can have multiple benefits, including reducing the air stuffiness inside homes, mitigating the risk of exposure to indoor-generated pollutants, improving thermal comfort and saving energy.

The evidence collected supports the need for further investigations, particularly in the following areas:

- Complementing the analysis with energy use patterns to identify additional measures to reduce energy use;

- Using existing data to identify the causal factors of energy poverty/vulnerability to support the development of policies to address this urgent issue;
- Exploring the connections between energy, comfort and health indicators and developing holistic frameworks to improve home conditions;
- Conducting intervention studies to investigate the effectiveness of specific measures in promoting beneficial behavioural changes, namely employing technological solutions for triggering warnings to occupants based on energy and IAQ real-time monitoring data.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en16041872/s1: Figure S1: Location of homes of families with children engaged for the PT pilot in the region of Porto (Northern Region, Portugal, Southern Europe). Table S1: Statistical analyses results.

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